A Review of the Variations of Optical Remote Sensing Conditions over Estonia in 1958-2011

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***Abstract*– The major restricting factor for space-born optical remote sensing at moderate and high latitudes is cloudiness. Significant intraseasonal and interannual differences in cloud amount and dominant cloud types are met. Cloud-free episodes are infrequent. The study of cloud restriction over Estonia was performed using hourly cloud detection data from Tartu-Tõravere meteorological station (58°16’N, 26°28’E, 70 m a.s.l.) in 1958-2011. Major features of sky coverage by almost nontransparent low and medium level clouds are considered. Monthly mean amounts of these clouds in October to February are above 7 tenths. Maximum mean coverage, close to 8.5 tenths, is reached in November. In spring and summer the mean coverage is usually between 5 and 6 tenths. The spaces of sky free from two lower level clouds often are partly covered by semitransparent cirrus clouds. Monthly relative coverages by cirrus clouds were studied statistically for March to September. Relative monthly mean cirrus cloud coverage of free spaces above one tenth was the largest, 0.40, in April and the smallest, about 0.30, in July. Overall mean coverage for March to September was 0.35. The days suitable for optical remote sensing were defined as those with cloudless conditions within ± 2 hours from noon when remote sensing activities usually are performed. The monthly averages and extremes of those days are presented as well as their time evolution in four seasons during 1958-2011. The probability of cloudless conditions is the highest in March when nearly 4 suitable days are met on average. The probability decreases from March to November and since then the conditions start to improve. In November the remote sensing conditions are available in less than half of the studied years and in March in about 90 percent out of all considered years. Monthly maxima of suitable days in all months were above 5.**

Keywords- Remote Sensing; Cloud; Solar Radiation; Meteorological Conditions; Suitable Days for Optical Remote Sensing

I. INTRODUCTION

Optical remote sensing of the Earth surface from space needs favorable atmospheric conditions for making the activities possible and avoiding uncertainties related to changing atmospheric transparency over scenes. A similar problem was actual in astronomy before the “earth remote sensing era”. Fast development in astrophysics since 1950s and worsening of observing conditions in observatories placed close to towns caused building of new astronomical observatories at remote sites preferably offering more cloudless and stable atmospheric conditions. Special astroclimatic studies at candidate sites were carried out to select the ones presenting most favorable atmospheric conditions. The principal stages of astroclimatic studies concerned with choosing the sites for astrophysical observatories in Caucasus and Crimea are described in recently issued paper [1] and these for other sites in several earlier publications [2-4]. Estimation of the availability of relevant conditions for observing the Earth from space may be considered as the “remote sensing climate”. One of important astroclimatic quantities is the number of nights suitable for observations. In optical remote sensing the number of days suitable for remote sensing may be considered as a similar indicator. The remote sensing conditions are far from being equal at different geographical regions. However, the remote sensing results are necessary also at regions where the weather conditions are rather bad. Some problems of remote sensing need relatively high frequency of coverage or collecting data in certain phenological phases of plant cover. Some objects are better distinguished in the presence of snowcover.

When the sky is overcasted by low and medium level clouds, the optical remote sensing of land surface is impossible or restricted to the free spaces between clouds. Within spaces free from two lower level clouds the data quality may be restricted by partly transparent upper level clouds. Finally, certain restrictions of the reliability of results may occur even in fully cloud-free conditions. The spatially and temporary varying aerosol optical depth (AOD) and its distribution by wavelength may be a reason of significant uncertainties in atmospheric correction of data.

The remote sensing conditions are closely related to the availability of solar irradiance on what we have published several papers, both on the availability of broadband irradiance as well as on the availability of ultraviolet irradiance [5-12]. In the present paper the results of statistical investigation of interannual and intraseasonal variations of the amounts of almost nontransparent low and medium level clouds as well as of the coverage by cirrus clouds of sky spaces free from two lower level clouds are presented and discussed. The considered period 1958-2011 includes 54 years. The results are based on hourly cloud visual detection data collected at Tartu-Tõravere meteorological station (58°16’N, 26°28’E, 70 m a.s.l.) located not far from the weighted geographical centre of Estonia. Total area of Estonia is about 45 000 km^2. The landscape around consists of arable land, grassland and forest. Cloud detection has been performed also at several other meteorological stations but with lower time resolution. Comparison of data from different stations has revealed that over some other parts of Estonia the sky may be to some extent cloudier. Over islands

located in western part of territory the sky tends to be to some extent less cloudy than at the Tartu-Tõravere meteorological station [13]. The differences are not large and the conclusions made on the basis of Tartu-Tõravere data can be considered representative enough for the whole country.

II. MATERIALS AND METHODS

A. Cloud Data

In the early 1950s the Tartu-Tõravere meteorological station was specializing on solar radiation measurements. The first attempts of recording sunshine duration were made at Tartu since 1906 [14]. First regular measurements of solar irradiance were performed in late 1930s and continued after the World War II since 1950 [15]. Before 1965 the station was based closer to Tartu than its present site at 20 km from the town center. The landscape around was similar to that at the present site. For solar irradiance measurements the Yanishevski AT-50 actinometers and Savinov-Yanishevski M-115 pyranometers were used until 1996 but were since replaced by the Eppley Labor. Inc. pyrheliometers and Kipp & Zonen pyranometers. The absolute accuracy of the ventilated Kipp & Zonen pyranometers is about ±2% and that of the pyrheliometers ±1%. In the case of older instruments these uncertainties usually were doubled. In the past intercalibration of sensors was regularly performed in Voeikov Main Geophysical Observatory (St. Petersburg, Russia), whereas now it is done in World Radiation Center (Davos, Switzerland). Cloud data were collected as auxiliary information for interpreting the solar radiation measurements.

Since July 1957 the hourly visual cloud detection at all three basic altitude levels was performed being unique among meteorological stations of the former Soviet Union. These visual cloud observations containing no gaps since the beginning are continued at present time when the station belongs to the Baseline Surface Radiation Network (BSRN). The clouds are detected half past each hour in local solar time. The cloud amounts in tenths as well as the dominating cloud types are noted down. From the beginning of cloud observation the total coverage of sky as the whole as well as the coverage at all basic levels was performed in tenths. As the clouds on two lower levels are almost nontransparent we consider their total amount separately from the upper level clouds. Daily average sky coverage by low and medium level clouds was calculated considering the data from observations within the range ±0.5 hours from the sunrise to ±0.5 hours from the sunset. Treating the daily cloud data we noted down roughly also the changes in major cloud types during a day as well as longer clear episodes. In warm and more sunny summer half-year the clear episodes appeared with higher frequency in early morning and late evening and much less frequently around noon [12]. The reason is development of convective clouds over the nonuniformly heated surface with increasing solar elevation. In cold and dark winter half-year the frontal overcast cloudiness dominates and clear episodes do not manifest preferred time during a day.

B. Main features of Sky Coverage by Low and Medium Level Clouds

In previous treatments of the Tartu-Tõravere meteorological station cloud data the separation was made between total clouds and low clouds. Also the long-term trends of dimming and brightening were analyzed [16, 17]. The contribution of middle level clouds together with that of upper level clouds was included in total clouds [18, 19]. The treatment and analysis were performed on the monthly level. In the present work the monthly averaging of the daily average values of sky coverage by the sum of low and medium level clouds were supplemented by the averaging additionally over ten day intervals in each month. In February the last 10-day interval includes 8 or 9 days and in months consisting of 31 days 11 days, respectively. A matrix of sky coverage by sums of low and middle level clouds consisting of 1944 points and exposing 36 ten-day intervals in each of 54 years is presented in Figure 1. One can see that the summarized cloud cover at two lower levels is very variable. The probability density distributions of ten-day averages over the considered 54 years were in all cases negatively skewed. The skewness varies in range from -0.003 to -2.05, being most frequently around -0.60. Due to small negative skewness almost in all cases the median of distribution is by 0.1 to 0.4 tenths larger than the mean. Both the sharper and the flatter distributions than the Gaussian were found. Maximum coverage of sky exceeding 8 tenths on average is reached in November. Since then it decreases to the value around 5 tenths in last decade of April. Approximately the same average coverage persists until the middle of June when it increases by 0.5 tenths and remains on the same level until the middle of August. The year-to-year variations of ten-day averages are large. In all months are met the episodes when the total amount of low and medium level clouds is small. Those situations present potentially higher probability for successful remote sensing activities. The lowest ten-day average amounts of low and medium levels clouds in March to August were below or slightly above 1 tenth. Maximal amounts during the same period were above 9 tenths in March, April and August and around 8.5 tenths in June and July. The lowest maximal ten-day average coverage by low and medium clouds, 7.5 tenths, was found in May. In September to February the minimal ten-day average amounts of low and medium level clouds varied in range between 1.8 and 2.6 tenths. Maximal values at the same time reached 10 tenths. In the cold and dark part of year, October to February, overcast conditions are met more frequently than during the period March to September.

C. Upper Level Clouds

When the sky is free from low and medium level clouds there remains a possible restriction of remote sensing by the cirrus clouds. Major features of cirrus cloud amounts on the monthly level as well as year-to-year variations of their amount at the study site in 1958-2003 were discussed in our work [4]. Here the data from years 2004-2011 have been added and a new survey was made. The results from the extended data set are very close to the previous ones. The representativeness of monthly cirrus cloud amount depends

on the number of days in the current month suitable for cirrus detection and on the spaces free from low and medium level clouds on these days. The days with the averaged value of free spaces above 1 tenth were accounted in further cirrus cloud detection. As was described in our previous work on cirrus clouds, a stronger criterion, accounting for those days with the average value of free spaces above two tenths, was also applied. The numbers of days in month suitable for cirrus detection occurred in most cases by two days smaller for the stronger criterion. Also the monthly average free spaces occurred by nearly 0.5 tenths larger. However, the monthly cirrus coverages of free spaces did not show differences exceeding 0.15 tenths. In the present work we used only a threshold 1 tenth for the free spaces. Monthly averages, StDev limits, maxima and minima for those days are presented in Figure 2. The time evolution of their annual sums during period March to September (214 days) in 1958-2011 is presented in Figure 3. The monthly averages of spaces free from low and medium clouds with StDev limits, maxima and minima are presented in Figure 4. The time evolution of average free spaces for March to September in tenths is presented in Figure 5. In this case the mean of monthly average values over seven months was used for characterization of each year out of the studied 54. Similarly the relative coverages of free spaces by cirrus clouds were treated and presented. Here is necessary to mention that here we considered only the days with free spaces above one tenth but in constructing the Figure 1 all days in month, because the relative low and medium cloud amounts are systematically larger.

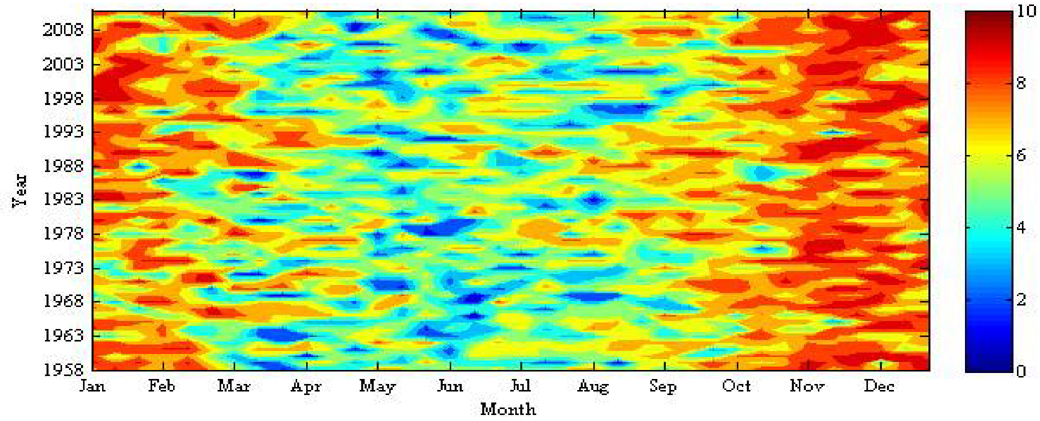

Figure 1 Averaged over ten days amounts of low+medium level clouds in tenths during 1958-2011

The detected free spaces may be fully, partly or not covered by upper level clouds. All these situations really were met. We use the monthly relative coverage of free spaces by cirrus clouds. This characteristic does not depend on the size of free spaces. The episodes when the relative coverage is small or even zero during several following days were met as well as the episodes of prevailing large relative coverages of free spaces. The monthly relative coverage of free spaces by cirrus clouds depends on the proportions of different relative coverages. The monthly mean cirrus cloud coverages with the evolution of March to September averaged relative coverage is presented in Figure 7.

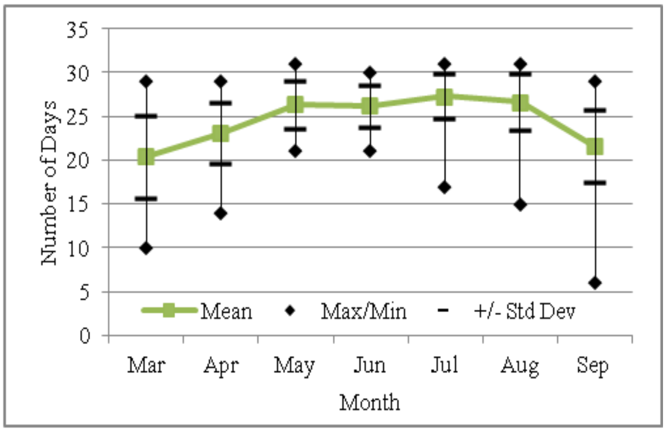

Figure 2 Number of days in month with daily average free spaces in low+medium clouds above 1 tenth. Monthly average, StDev limits, max and min

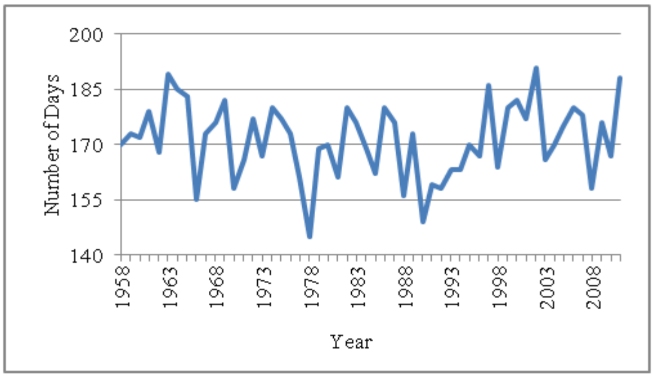

Figure 3 Time evolution of March to September (214 days) annual total number of days with daily average spaces in low+medium clouds above 1 tenth

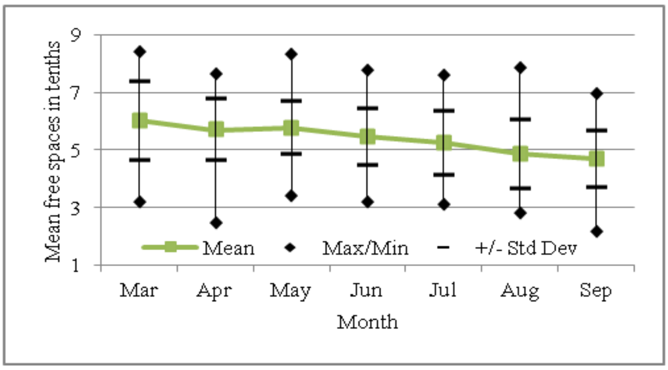

Figure 4 Monthly average spaces free from low+medium clouds, in tenths. Monthly average, StDev limits, max and min

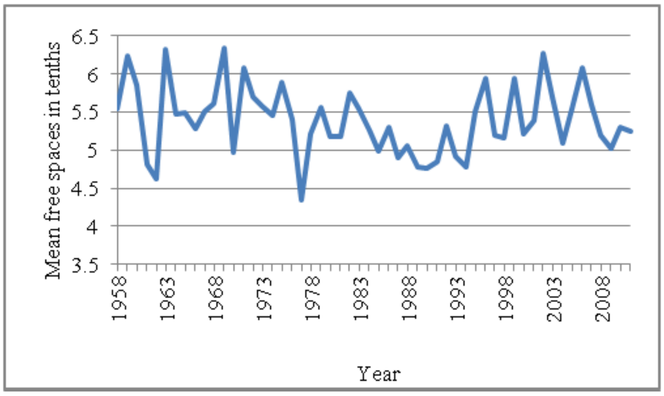

Figure 5 Time evolution of March to September spaces free from low+medium clouds, in tenths

D. *Suitable Days for Optical Remote Sensing*

Optical remote sensing depends on the sun as the sole source of illumination. The sun-synchronous orbits are preferred to cross the regions at the same solar time. Very low and very high solar elevations are usually avoided. At the study latitude the crossing time is within a few hours from the noon. From these considerations the acceptable conditions for remote sensing are when there are cloud-free conditions around noon.

Using the local cloud observation data from our cloud database the days presenting cloud-free conditions within ± 2 hours from the noon were selected as the suitable days for remote sensing. The selection was done by visual checking of the dataset where the cloud free episodes as well as the overcast intervals and major cloud types in partly cloudy conditions are presented. In most cases these days are almost cloudless but the minor part is cloudy before or later of the considered interval. The first two columns in Table 1 present the monthly mean and maximal number of days suitable for optical remote sensing. In the third column the number of years out of 54 with no days suitable for the optical remote sensing in current month is presented. The last column presents the same in percent scale.

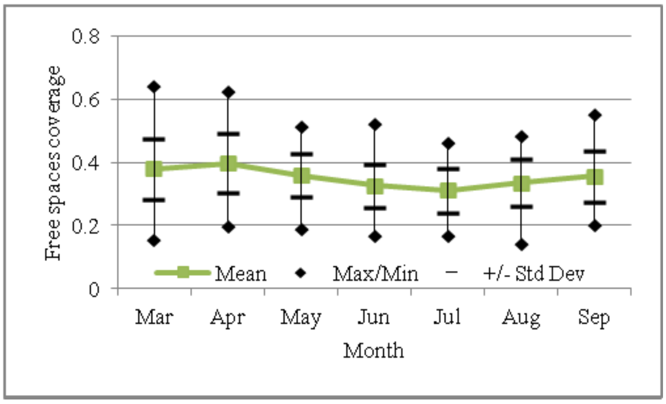

Figure 6 Relative coverage of spaces free from low+medium clouds by cirrus. Monthly average, StDev limits, max and min

The annual amounts of days suitable for optical remote sensing were calculated as the sums of monthly numbers. Similarly the numbers of those days in different seasons were found. The winter season contains January to March, the spring season April to June, the summer season July to September and the autumnal season October to December. Time evolution of annual numbers of suitable days is presented in Figure 8 and the time evolutions of seasonal numbers in Figure 9.

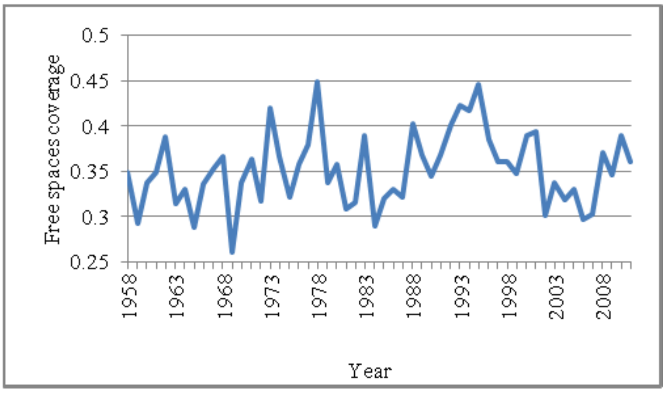

Figure 7 Time evolution of March to September relative coverage by cirrus of spaces free from low+medium clouds

III. RESULTS AND DISCUSSION

A. *Low and Medium Cloud Intraseasonal and Interannual Pattern*

The pattern of averaged over ten days' sums of low and medium level cloud manifests significant interannual variations.

TABLE I MONTHLY AVERAGES AND MAXIMA OF DAYS SUITABLE FOR OPTICAL REMOTE SENSING IN 1958-2011. NUMBER OF YEARS OUT OF 54 AND PER CENT OF YEARS PRESENTING NO SUITABLE DAYS. THE SAME ON SEASONAL SCALE

Month	**Average**	**Maximum**	**Years with No Suitable Days**	
			Number	***Per cent***
January	2.07	6	11	20.4
February	2.41	9	17	31.4
March	3.83	14	6	11.1
April	2.78	7	9	16.7
May	3.09	10	9	16.7
June	2.52	8	13	24.1
July	2.61	13	15	27.8
August	1.65	11	18	33.3
September	1.52	5	19	35.2
October	1.61	9	20	37
November	1	8	28	51.9
December	1.54	6	14	25.9
Winter	8.31	20	0	0
Spring	8.39	17	0	0
Summer	5.78	20	3	5.5
Autumn	4.15	13	2	3.7

The autumnal months, especially November and December, are cloudier than the remaining ones. In October

the range of variation of averaged cloud amount was between 3 and 9 tenths. Since 1996 the interannual variations tend to be similar to those in 1958-1968 and small values appear more frequently than in years 1969-1995. Since the third ten-day interval of October, the range of interannual variations decreases and remains between 6 and 8 tenths. In November also the range of variation remains within two tenths Often January and February are also heavily cloudy. In cold winters with frequent domination of high pressure the monthly average low and medium cloud amounts are significantly smaller than in warm cyclonic winters. Small amounts appeared in January more frequently in 1963-1987. In the first two ten-day intervals of January the low and medium cloud amounts have increased in last 25 years. In the third ten-day interval no such tendency was found. In February the smaller coverages appeared more frequently before 1985. However, the overall lowest value in the third ten-day interval was recorded in 2011.

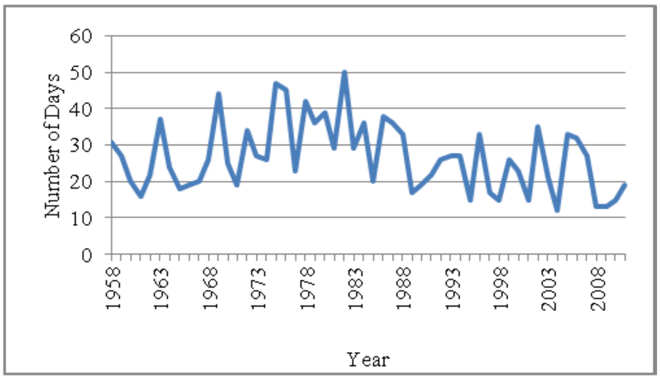

Figure 8 Annual numbers of days suitable for optical remote sensing

In March the coverage of sky by low and medium level clouds decreases and the range of interannual variations increases. In April the range continues to decrease. Relatively small coverages were met more frequently before 1970 and in two recent decades. During the two last ten-day intervals the interannual variations in last 20 years are similar to those before 1970. In May and June the range of year-to-year variations is large. In very recent years, the variations have been small. In May the range of variation in 1970-1995 was notably larger than earlier and later. In June the interannual variations have been the smallest among months in the year.

In July the contrasting small and large average cloud coverages cause the bimodality of distribution separating cloudy and relatively fine weather years. In 1960s-1970s and in recent 15 years the smaller averaged cloud amounts are met more frequently than in period from late 1970s to the middle of 1990s.

In sunny summers like those in 1960s to early 1970s and since 1994 the autumnal cyclonic period causing increase in cloud amount tends to begin later than in years 1976-1993 manifesting wetter and cloudier summers [6]. In the 13 sunniest summers the cloud amount has noticeably increased after the first ten-day interval of August only in two cases. In other 11 (85 %) cases the increase in daily average cloud amount has happened after the first (6 cases) or second (5 cases) ten-day interval of September. Vice versa, in summers exhibiting average or above average cloud amounts the sunny periods tend to appear before the middle of July. Only in 7 cases of total 39 (18 %) the first or second ten-day interval of September has been relatively sunny.

The quasiperiodic weather variations in different scales are met in all seasons. They depend on the activity of westerly flow and on development and persistence of anticyclonic situations. The major contributors to the weather variations in winter are the Arctic Oscillation (AO), the North Atlantic Oscillation (NAO), the Arctic Polar Vortex or circumpolar vortex strength, the Northern Hemisphere Winter Storm Tracks intensity and the Atlantic meridional overturning circulation (MOC). In the positive phase of AO more of atmospheric mass is located over midlatitudes and less over Arctic. Sea level pressure and the weather are strongly correlated with the AO index only in AO Core Region of strong westerly flow [20]. In the negative phase of AO the pressure difference and the westerly flow are weaker. A prolonged positive period in the smoothed AO index has been observed in 1988-1995.

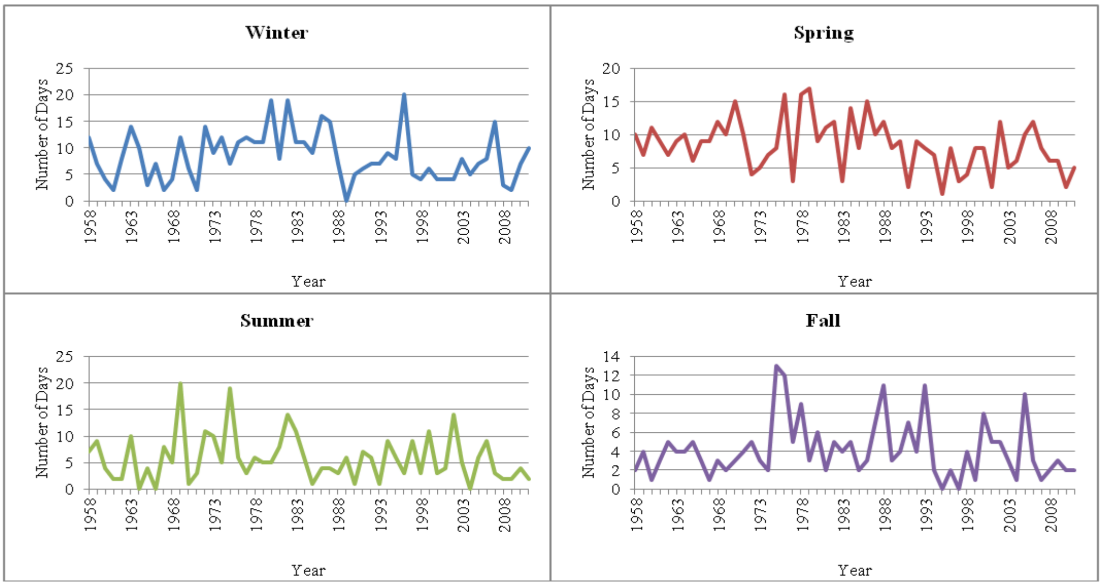

Figure 9 Seasonal numbers of days suitable for optical remote sensing

The NAO as a dominant mode of the atmospheric behaviour in the North Atlantic sector is a large-scale alternation of atmospheric mass with the centers of action near the Icelandic low and the Azores high. After 1980 an eastward shift of action centers has been noticed. Often a steady relationship between the NAO and key climate parameters of the North Atlantic and Northern Europe is expected. These relationships are really variable in time and tend to be more complex than previously thought [21]. The NAO in winter is confined to the Atlantic sector during low solar activity, whereas it tends to have a wider hemispheric AO like structure during high solar activity [22, 23]. Significant correlations between the heat transport in the North Atlantic Ocean and atmospheric processes over the Nordic Seas and the Eurasian continent have been found for periods 25 years and longer [24]. The heat anomalies propagate along the cyclone tracks towards northeast. The oceanic influence on the North Atlantic climate has been nonstationary [25]. The Northern Hemisphere surface temperatures have shifted to the larger warming since 1970 [26] and since the late 1980s the cloud amounts in winter have increased in regions that are exposed to the westerlies [27]. The eastern Europe experienced an advanced annual cycle of spring near-surface temperature in 1978-2010 [28].

B. Cirrus Cloud Distribution Within March to September Period and Interannual

In days when the amount of low and medium level clouds is small significant restrictions of optical remote sensing conditions occur due to cirrus clouds. In some cases cirrus clouds are met also in very small amounts. But in other similar cases most of the free spaces in lower level clouds are filled by cirrus. The monthly average coverage of sky spaces free from low and medium clouds by cirrus was impossible to detect in October to February when overcast days are met too frequently. In the favorable months the number of such days increased from relatively large value in March to the maximum in April and then decreased to minimum in July with following slight increase in August and September. The interannual variations of relative coverage of free spaces of sky by cirrus were the largest in March and then decreased to minimum in July and August with the following increase in September. The smallest monthly coverages by cirrus remained in range 0.15 to 0.2, while the monthly largest values decreased from 0.65 in March and April to 0.45 in July with the following increase to 0.55 in September. Standard deviations are to somewhat larger in March and April and almost equal in other months.

Averaged over the period from March to September values of coverage by cirrus clouds varies within range 0.26 to 0.45 with the mean value 0.35. Usual range of deviations in separate years is within ±0.05. Longer compact period of positive deviation in years 1992-1996 is very probably related to the increased concentration of cloud condensation nuclei formed by falling sulphate aerosol after the Pinatubo 1991 eruption. The influence of the volcanic aerosol on cirrus cloud microphysics is discussed in [29] and the transport from tropics to midlatitudes in [30].

C. Amounts of Suitable Days for Remote Sensing

The amount of days in month suitable for optical remote sensing depends on weather conditions. The annual average number of those days at the study site was 26.7 and their maximal number was 50. Two most minimal annual values, 12 and 13, were recorded in recent decade, in years 2004, 2008 and 2009. The monthly average number of such suitable days was the smallest, only one, in November and then increasesd reaching maximum 3.8 in March. In April it occurs somewhat smaller than in May and then decreases toward the autumnal months. Maximum number, 14, was also recorded in March. The second and third monthly largest values, 13 and 11, were recorded in July and August, respectively. In all months certain part of years present no days suitable for remote sensing. In the Table 1 their number out of 54 as well as the relative amount in percent scale are presented. The smallest percent was found in March, which is the most favorable month, by the remote sensing conditions. The next two best months were April and May. In January the amount of nonsuitable years is smaller than in December and February. In winter months the numbers of days suitable for remote sensing increases in the presence of cold high pressure conditions. In warm cyclonic winters the favorable conditions appear in very rare cases. In spring months April to June at least one suitable day for remote sensing in year was found. The maximum number of those days reaches 17 what is smaller of that in winter and summer but interannual variation is the smallest among seasons. In winter high values appear due to the large contribution of March. In the period March to September the daily average spaces free from low and medium clouds decrease. The major contribution to this decrease comes from the hours around noon. As a result in summer months the conditions for remote sensing are more restricted than these in late winter-early spring and partly even in early autumn. In October and in some few cases in early November the conditions for optical remote sensing have occurred better than in less cloudy on average summer months despite that in more than 50% of years there have been no days suitable for remote sensing in November. In October the number of suitable days in 5 cases have reached 6 or 7 and in one exceptional case even 9. In July, August and September the numbers above that level also have been very exceptional.

IV. CONCLUSIONS

Over Estonia located at subpolar latitude in the zone influenced by polar front and North Atlantic storm track the conditions for optical remote sensing are moderate. The monthly numbers of days suitable for remote sensing activities tend to be relatively small and manifest significant interannual variations. For each month a certain percent of years with no such days was found in the period 1958-2011. The percent was the highest (more than 50% of all studied years) for November and the smallest (slightly exceeding 10) for March.

The most stable conditions for optical remote sensing with the largest average number of suitable days in month and the smallest percent of years presenting no suitable days were met in March. The monthly average number of suitable

days decreased from nearly four in March to one in November.

In separate years the favorable conditions for optical remote sensing may exist in all months but with different probability.

Despite the fact that the daily average amounts of low and medium level clouds are smaller in spring and summer months as compared to the autumnal and winter ones the conditions for optical remote sensing in summer are not the most favorable. In June and July about 2.5 suitable days in month have been met and in August to October only about 1.5 such days in month on average. The amount of years with no such days in month for the last interval exceeded 1/3 out of all considered years. In June and July their relative contribution was slightly above 1/4 out of all years.

In summer months the cloud amount increases around noon due to the development of convection. The amounts of convective clouds are smaller during the extended dry periods and larger in wetter periods. The coverage of free spaces of sky also tends to be smaller in extended dry periods and larger in wetter ones.

Since the late 1980s the conditions for optical remote sensing at the study site have rather worsened in winter and spring as well as on annual level. Bad conditions have frequently met also in summer and fall.

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